

## *Bose-Einstein Condensation*

### **Preface**

Among the most remarkable effects that quantum mechanics adds to the catalog of the thermal properties of matter is the “condensation” of an ideal gas of identical particles into a single quantum state, the principle of which was discovered in the theory of statistical mechanics by Bose and Einstein in the 1920s.

Bose-Einstein condensation (BEC) is thus a mechanism for producing a macroscopic quantum system, and is exemplary of the macroscopic quantum phenomena of superconductivity and superfluidity. However, it has proven most difficult to attain BEC in the laboratory vs in the theory of the ideal gas. As discussed in the first article of this Special Issue, the basic criterion for BEC is that the typical distance between particles be comparable to or less than their deBroglie wavelengths; and in virtually every real material system, the effects of interparticle interactions become very strong when this criterion is attained, and the model of a ideal quantum gas is inapplicable.

The quest to produce BEC in dilute atomic gases began in the early 1980s with work on spin-polarized hydrogen. During the past decade, experimental techniques for optical trapping and cooling of atomic gases were developed to a high degree, and the combination of these techniques with evaporative cooling made it possible to attain BEC in dilute alkali vapors. The first successful such experiment, using rubidium, was performed at JILA, a joint institute between the National Institute of Standards and Technology (NIST) and the University of Colorado; its dramatically illustrated results were published in the scientific literature in July 1995, and immediately stimulated intense activity in the physics community and considerable interest among the public at large.

The first article in this Special Issue of the NIST Journal of Research contains the story of that experiment as told by the leader of the NIST effort, Eric Cornell. This article is an edited transcript of a colloquium presented by Dr. Cornell to a nonspecialist audience, and it conveys the sense of excitement that currently pervades the field in terms that are accessible to the general reader. The scientific rationale for BEC studies and the prospects for their practical application are aptly summarized in the concluding section of this article.

The year following the original discovery of alkali gas BEC has seen the production of BEC in at least one other gas, a growth by three orders of magnitude in the maximum attainable number of condensate atoms, and the beginning of experiments that probe BEC properties in detail. Such work continues at a rapid pace as this issue goes to press. About 200 papers on BEC have appeared on electronic preprint archives and in the scientific literature since the initial JILA report. Much of the excitement in this field is driven by its combination of elements of different subfields of physics—atomic, optical, condensed matter, statistical, even elementary particle—whose separate practitioners do not often identify a common topic as a cutting edge of research in their own fields. This Special Issue of the NIST Journal of Research is an attempt to assemble such diverse views in one package, which is a challenging enough task at this time—it will take somewhat longer to see broad agreement on issues emerge from such a group!

Dr. Cornell’s paper is a general introduction to the field of gaseous BEC. The other papers in this issue deal with four of the major themes with which this field is concerned, and they are presented in groups. The first group consists of reinvestigations of standard BEC theory, typically focussing on issues (such as inhomogeneity of the density) that were peripheral in the original theory of a uniform ideal gas, but are central to understanding the behavior of alkali BECs. The second group deals with the physics of atomic collisions at ultracold temperature, a topic that is extremely challenging both in theory and experiment, and is key to the understanding of alkali BEC at the microscopic level. Third is a group of papers that deal with quantitative modeling of BECs based on the microscopic parameters that are determined by collision physics; these provide the specific tests of current theoretical understanding against the results of experiment. Last are several papers that explore the BEC/laser analogy mentioned in the conclusion of Cornell’s article; practical exploitation of this analogy to develop a coherent source of matter waves or “atom laser” is one of the principal goals of current laboratory work.

Though by no means comprehensive, this collection of papers provides a representative introduction to current work on BEC. For secretarial and editorial assistance in its production, the editors are grateful to Mrs. Aija Roess, Mr. Robert Dodd, and the production staff of the NIST Journal of Research.

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